

# LTC4041

## 2.5A Supercapacitor Backup Power Manager

## DESCRIPTION

Demonstration circuit 2642A shows the [LTC4041](#) supercapacitor backup power manager operating with either a stack of two series supercapacitors (DC2642A-A) or a single supercapacitor (DC2642A-B). The board demonstrates the design of a 5V rail with a short-term power backup using 10F supercapacitors.

The input current limit, charge current limit, charge voltage, power fail threshold, and boost voltage are all configurable

through changing resistor values on the board. Test points for all monitoring pins and LED indicators on status pins are also available to assist in the evaluation.

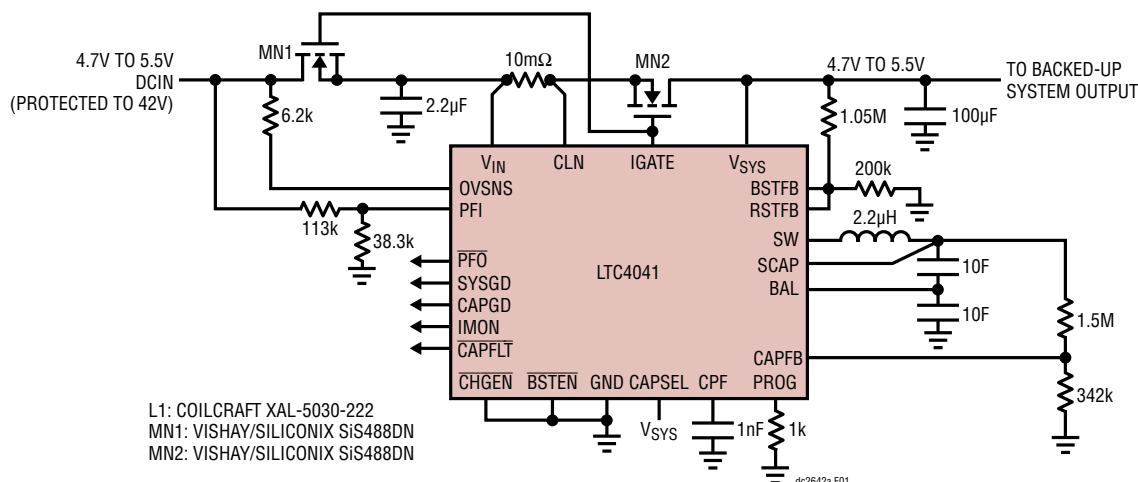
**Design files for this circuit board are available at**  
<http://www.analog.com/DC2642A>

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## PERFORMANCE SUMMARY

| SYMBOL             | PARAMETER                    | CONDITIONS   | MIN | TYP                     | MAX | UNITS |
|--------------------|------------------------------|--|-----|-------------------------|-----|-------|
| DCIN               | Input Voltage Range          | $V_{PF} = 4.7V$  | 4.7 |                         | 5.5 | V     |
| DCIN <sub>OV</sub> | DCIN Overvoltage Limit       |  |     |                         | 42  | V     |
| V <sub>BOOST</sub> | Backup Boost Voltage         | $R5 = 1.05M\Omega$ , $R2 = 200k\Omega$                                     |     | 5                       | 5.5 | V     |
| V <sub>SYS</sub>   | System Voltage               | $V_{IN} > V_{PF}$ (with Hysteresis)<br>$V_{IN} < V_{PF}$ (with Hysteresis) |     | $V_{IN}$<br>$V_{BOOST}$ |     | V     |
| V <sub>PF</sub>    | Power Fail Threshold Voltage | $R1 = 113k\Omega$ , $R2 = 383k\Omega$                                      |     | 4.7                     |     | V     |
| I <sub>IN</sub>    | Input Current Limit          | $RS1 = 10m\Omega$  |     | 2.5                     |     | A     |
| I <sub>SCAP</sub>  | Charge Current Limit         | $R_{PROG} = 1k\Omega$  |     | 2                       | 2.5 | A     |

## TYPICAL APPLICATION



# DEMO MANUAL DC2642A

## QUICK START PROCEDURE

Refer to Figure 1 for the proper measurement equipment setup and jumper settings. Please follow the procedure below to familiarize yourself with the DC2642A.

1. Connect test equipment as shown in Figure 1. Ensure JP1 and JP2 are both in the ON position.
2. Enable PS1 and observe as the voltage on VM2 begins to rise. The voltage on VM1 should be approximately 5V. The CAPGD LED will turn on to indicate that the supercapacitor voltage is not yet in regulation.
3. Observe that the voltage on VM2 regulates at a default 4.5V on DC2642A-A or 2.4V on DC2642A-B. At this point, the CAPGD LED will turn off.
4. Enable LD1, then disable PS1 and observe that the voltage on VM1 remains regulated at 5V. The voltage on VM2 will begin to fall.
5. Observe that the PFO and CAPGD LEDs turn on to indicate that the DCIN voltage has fallen below the 4.7V power fail threshold and the supercapacitor voltage has fallen out of regulation.
6. Eventually, the supercapacitor voltage will fall enough that the VM1 voltage will fall out of regulation. As VM1 falls past ~4.625V, the SYSGD LED will turn on briefly before VM1 falls out of regulation.

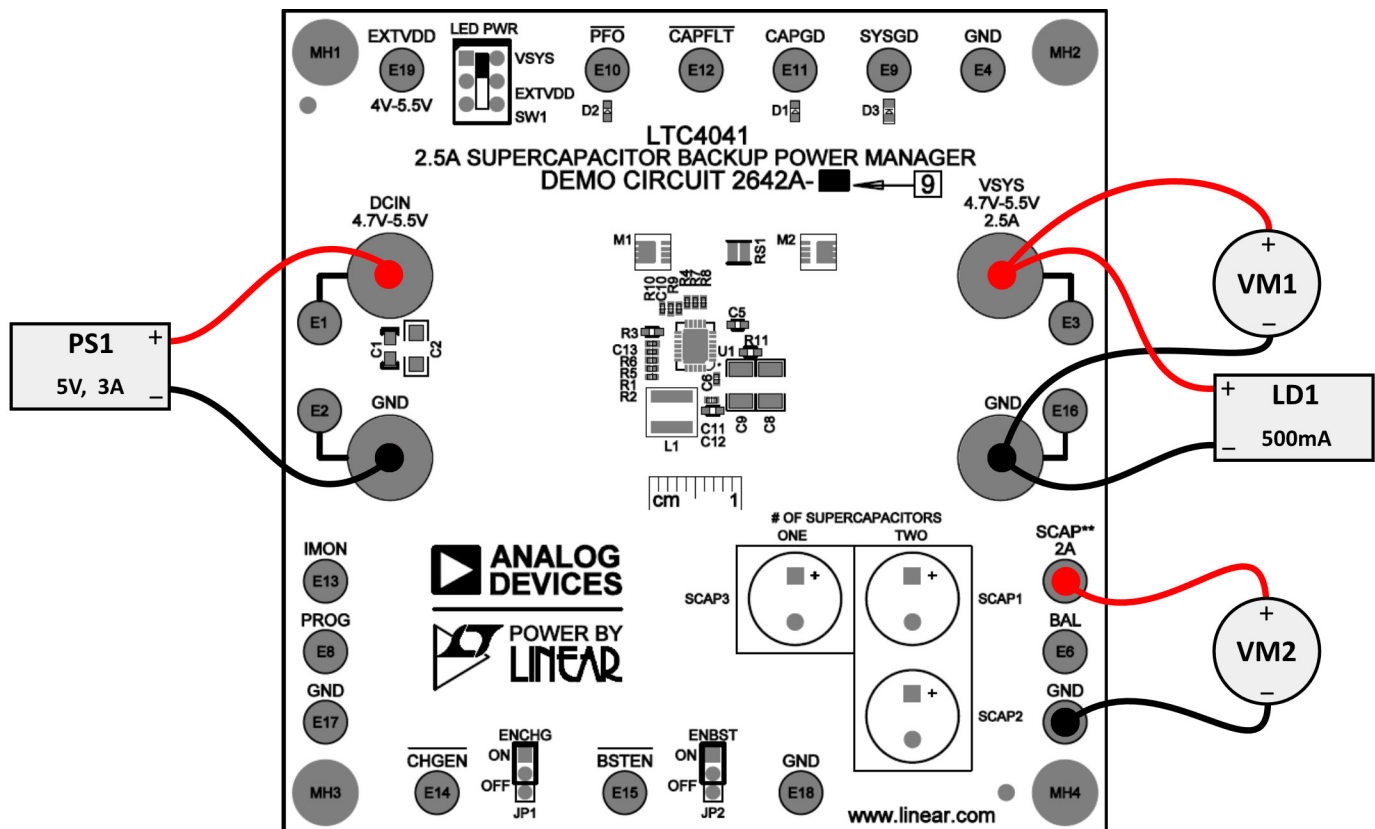


Figure 1. Quick Start Procedure Setup for DC2642A

## DEMO BOARD OPERATION

### DCIN Voltage Drops

Because the LTC4041's power fail function monitors the input voltage to determine its operation mode, it is important to use low-impedance connections to the demo board. Poor quality or lengthy wiring to DCIN can result in a substantial voltage drop across the wires as the DC2642A passes power to the load or charges the supercapacitor(s), leading to undesired triggering of the power fail threshold, 4.7V default.

Short, high-conductivity wires with a good connection are desirable and will mitigate this issue. As a workaround, the power fail threshold can be lowered or a higher voltage can be output from the power source to account for these drops, but this should not exceed the 5.5V rating of the DC2642A.

### Number of Supercapacitors

The LTC4041 can support either one or two supercapacitors. For safety reasons, DC2642A is broken into two variants: DC2642A-A has two supercapacitors and balancing enabled, while DC2642A-B has one supercapacitor and has no need for balancing.

The LTC4041 uses the CAPSEL pin to determine whether one or two supercapacitors are present and whether balancing should be enabled. The charger also features supercapacitor over-voltage protection, and the voltage limits are based on the number of supercapacitors present as indicated by CAPSEL.

As a result, it is imperative that CAPSEL is configured to correctly reflect the number of series supercapacitors in the system. Resistor jumpers (R19 & R20) on the back of the DC2642A allow the CAPSEL state to be configured according to Table 1.

**Table 1. Configuring Supercapacitor Count**

| Supercapacitor Configuration | Populated Footprint(s) | Populated CAPSEL Resistor |
|------------------------------|------------------------|---------------------------|
| Dual (Series)                | SCAP1 & SCAP2          | R19                       |
| Single                       | SCAP3                  | R20                       |

### Evaluating Power Consumption

When evaluating the power consumption of the LTC4041 using the demo board, it is recommended that SW1 is placed in the EXT<sub>V<sub>DD</sub></sub> position to disable the LEDs or power them externally.

### Discharging Supercapacitors

Throughout the course of evaluation, it may become necessary to discharge the supercapacitors. If possible, it is recommended that an electronic load is used to discharge slowly and safely.

Directly shorting the supercapacitors will not damage them, but can result in sparks and damage to the conductor causing the short.

### Removing Supercapacitors

The onboard supercapacitors can be moved into single-supercapacitor or dual-supercapacitor (series) configuration, or can be replaced with a user's own supercapacitor models. It is recommended that supercapacitors are discharged sufficiently before being removed.

### CHGEN and BSTEN Diodes: D4

D4 is used to diode-OR the voltages on  $V_{SYS}$  and SCAP to create a logic-high voltage for the  $\overline{CHGEN}$  and  $\overline{BSTEN}$  pins that will be available in situations where  $V_{SYS}$  is not present. This is necessary to disable the boost function ( $\overline{BSTEN}$  tied high), and it is also necessary to enter shutdown mode ( $\overline{CHGEN}$  and  $\overline{BSTEN}$  tied high). In applications where  $\overline{CHGEN}$  and  $\overline{BSTEN}$  are always tied to ground, the diode-OR is not needed.

## DEMO BOARD OPERATION

### Optional Components: R7 & R8

By default, the RSTFB input is fed the same voltage as the BSTFB input. The 0.74V threshold of the RSTFB pin is 92.5% of the 0.8V BSTFB servo voltage. As a result, tying both pins to the same voltage divider causes the SYSGD pin to pull low when the  $V_{SYS}$  voltage drops below 92.5% of the programmed backup boost voltage.

If a different threshold is desired, R4 can be removed to detach the dividers from each other, and R7 & R8 can be installed with values to set a custom SYSGD indication threshold.

### Backup Time

The amount of time that the supercapacitor can back up the system is influenced by many factors. The most prevalent are the supercapacitor voltage, the system boost voltage, and the system load current.

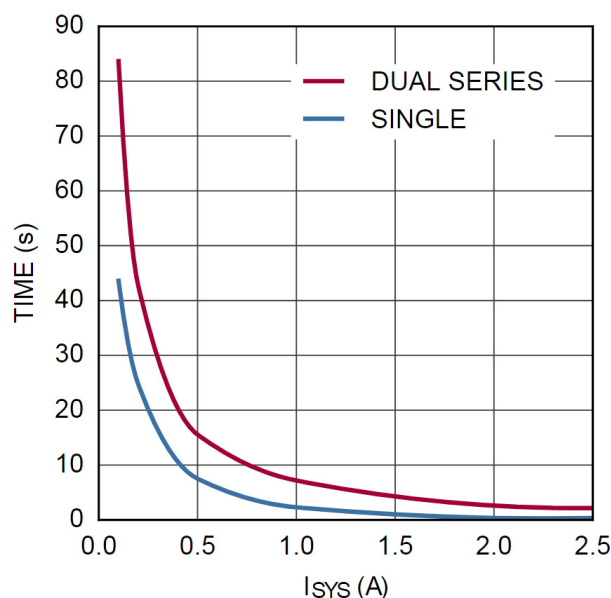


Figure 2. Measured Backup Time for Single/Dual 10F Supercapacitors (Boost to 5V)

However, other factors such as supercapacitor leakage and ESR can also play a significant role under some circumstances. An equation for estimating backup time is given in the LTC4041 data sheet, but it is still necessary to test operation with given values and components.

The backup time decreases as the load current increases, as expected. However, the decline in backup time is accelerated due to several of the aforementioned factors.

When using a single supercapacitor, the lower voltage limit of the supercapacitor and the fixed boost converter switch current of the LTC4041 will result in a shorter backup time when compared to two supercapacitors stacked in series.

### Switch Current Limit

At higher load currents with lower supercapacitor voltages, the LTC4041 will need to limit the supercapacitor's discharge current as to not exceed the current limit of its internal boost switch. This protects the IC, but  $V_{SYS}$  will begin to collapse when the switch current limit is reached due to power-limiting.

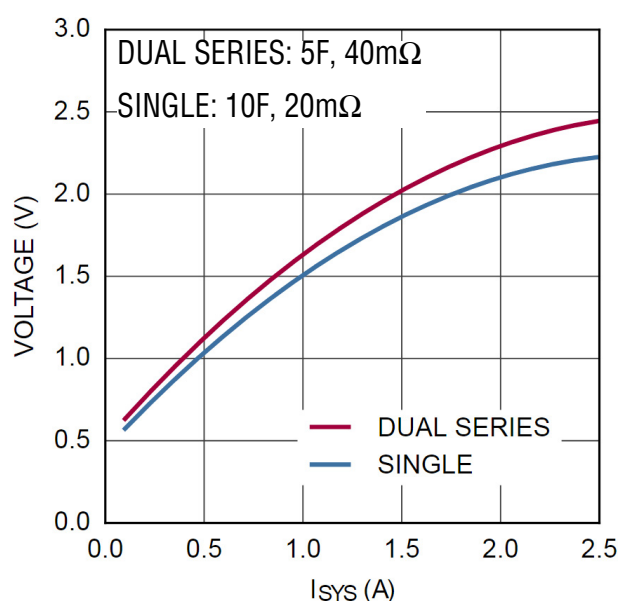
### Equivalent Series Resistance (ESR)

All supercapacitors have ESR which dissipates power and causes a voltage drop when they are being discharged. At lower supercapacitor voltages, the switch limit will be reached sooner, causing a faster collapse of  $V_{SYS}$ . For this reason, it is beneficial to select supercapacitors with low ESR. The 10F supercapacitors used on the DC2642A have a typical ESR of 20m $\Omega$ .

## DEMO BOARD OPERATION

In Figure 3, it can be observed that the dropout voltage for dual supercapacitors (in series) is greater than the dropout voltage for a single supercapacitor. This is because the ESR is greater for series-connected capacitors.

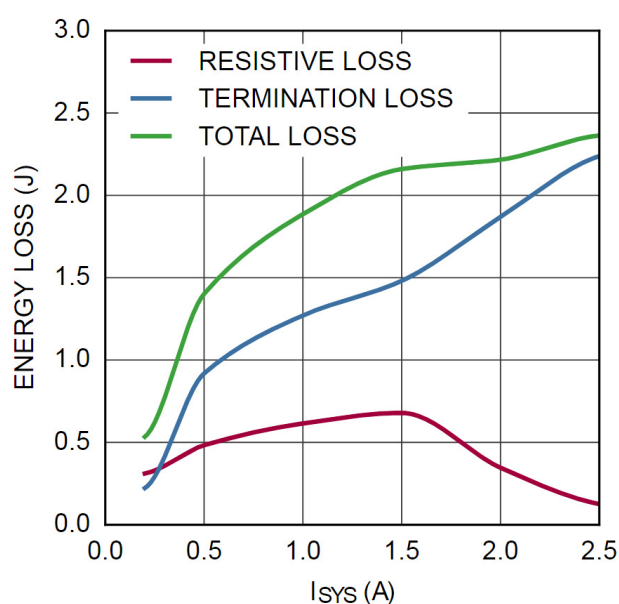
Figure 3 shows the voltage of the supercapacitor(s) at different  $V_{SYS}$  loads after  $V_{SYS}$  has dropped out, charging has terminated, and the supercapacitor voltage has relaxed. Charging terminates at the same voltage for both supercapacitors as seen by the LTC4041; however, the voltage drop across the ESR causes the supercapacitor voltages to appear lower when being discharged. As the current draw from the supercapacitors stops, the voltage across the ESR approaches 0V, and the supercapacitors relax to a voltage unaffected by ESR. A higher voltage after the supercapacitor relaxes indicates that more energy was unused when discharging.



**Figure 3. SCAP Voltage at  $V_{SYS}$  Dropout for Single/Dual 10F Supercapacitors (Boost to 5V)**

Figure 4 shows the measured losses due to ESR for a single 10F supercapacitor configuration. The total ESR losses are a combination of the resistive loss from the ESR and the energy unused as a result of early termination due to the ESR.

The amount of energy loss is particularly high for the single-supercapacitor case at higher load currents. This is due to the low starting voltage which gives little headroom to avoid the switch current limit.



**Figure 4. Energy Loss Due to ESR at Various  $V_{SYS}$  Loads (Single 10F, Boost to 5V)**

## Supercapacitor Leakage

Internal leakage in a supercapacitor is comprised of diffusion current and steady-state leakage current. Diffusion current decreases as the supercapacitor is held at a voltage. Manufacturers typically spec leakage at a certain time after the supercapacitor has been charged.

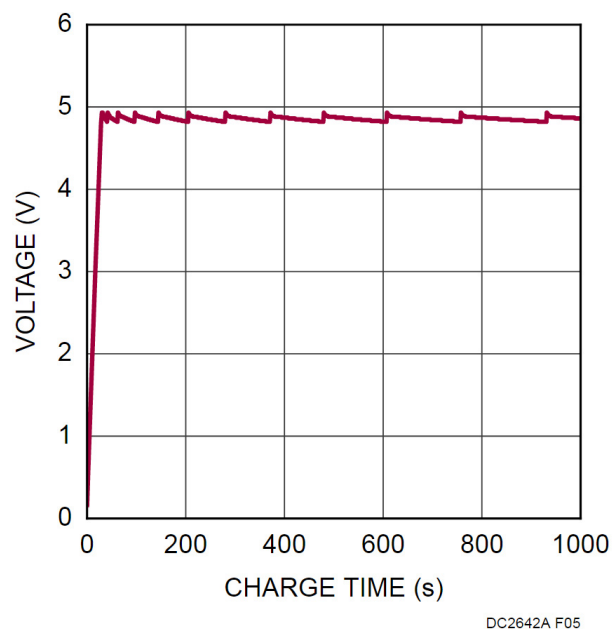
## DEMO BOARD OPERATION

The 10F supercapacitors on the DC2642A have a specified leakage current of 0.023mA after 72 hours of being held at the rated charge voltage. Near the start of charging, though, the leakage current is significantly higher.

Supercapacitor leakage is primarily a concern for backing up loads for a longer time. To test operation with worst-case leakage current, charge a supercapacitor and trigger a power-fail immediately after the supercapacitor reaches its full charge voltage.

Figure 5 shows the self-discharge of the supercapacitor triggering a recharge cycle. Note that the recharge cycles become less frequent as the supercapacitor remains near full charge.

Keeping these factors in mind, the LTC4041 can be used to design a robust 5V backup system using either a single supercapacitor or two supercapacitors in series. Given the effects of the switch current limit and the ESR of the supercapacitor model, using two supercapacitors in series is generally preferable when operating at higher load currents. However, designs with lower load currents can save space and lower costs by using a single supercapacitor.



**Figure 5. Supercapacitor Recharge Rate Due to Self-Discharge (Dual 10F, Unloaded)**

## PARTS LIST

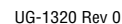
| ITEM  | QTY | REFERENCE     | PART DESCRIPTION   | MANUFACTURER/PART NUMBER                  |
|---|-----|---------------|--|---|
| <b>Required Circuit Components</b>              |     |               |  |   |
| 1   | 1   | C1            | CAP, 0.1 $\mu$ F, X7R, 50V, 10%, 0805  | AVX 08055C104KAT2A                        |
| 2   | 1   | C2            | CAP, 10 $\mu$ F, X5R, 50V, 10%, 1206   | MURATA GRM31CR61H106KA12L                 |
| 3   | 1   | C3            | 68 $\mu$ F $\pm$ 20% 50V Aluminum Polymer Capacitor Radial, Can - SMD 20m $\Omega$           | Panasonic Electronic Components 50SVPF68M |
| 4   | 1   | C5            | CAP, 2.2 $\mu$ F, X5R, 10V, 10%, 0603, NO SUBS. ALLOWED                                      | MURATA GRM188R61A225KE34D                 |
| 5   | 3   | C6, C11, C14  | CAP, 0.1 $\mu$ F, X7R, 10V, 10%, 0402  | MURATA GRM155R71A104KA01D                 |
| 6   | 2   | C8, C9        | CAP, 100pF, C0G, 100V, 5%, 0805  | AVX 08051A101JAT2A                        |
| 7   | 1   | C12           | CAP, 10 $\mu$ F, X5R, 10V, 20%, 0603   | AVX 0603ZD106MAT2A                        |
| 8   | 1   | C13           | CAP, 1000pF, X7R, 16V, 10%, 0402   | AVX 0402YC102KAT2A                        |
| 9   | 1   | D4            | DIODE ARRAY SCHOTTKY 40V SOT23   | Diodes Incorporated BAS40-05-7-F          |
| 10  | 1   | L1            | IND., 2.2 $\mu$ H, PWR, 20%, 9.2A, 14.5m $\Omega$ , 5.48mm $\times$ 5.28mm, XAL5030,AEC-Q200 | COILCRAFT XAL5030-222MEB                  |
| 11  | 2   | M1, M2        | MOSFET N-CH 40V 40A 1212-8   | Vishay Siliconix SIS488DN-T1-GE3          |
| 12  | 1   | R1            | RES., 113k $\Omega$ , 1%, 1/10W, 0402  | PANASONIC ERJ2RKF1133X                    |
| 13  | 1   | R2            | RES SMD, 38.3K $\Omega$ , 1%, 1/16W, 0402  | Vishay Dale CRCW040238K3FKED              |
| 14  | 1   | R3            | RES SMD, 6.2K $\Omega$ , 5%, 1/4W, 0603  | Rohm Semiconductor ESR03EZPJ622           |
| 15  | 1   | R4            | RES., 0 $\Omega$ , 1/16W, 0402   | ROHM MCR01MZPJ000                         |
| 16  | 1   | R5            | RES., AEC-Q200, 1.05M $\Omega$ , 1%, 1/16W, 0402   | VISHAY CRCW04021M05FKED                   |
| 17  | 1   | R6            | RES., 200k $\Omega$ , 1%, 1/16W, 0402  | PANASONIC ERJ2RKF2003X                    |
| 18  | 1   | R11           | RES., 1k $\Omega$ , 1%, 1/10W, 0603  | NIC NRC06F1001TRF                         |
| 19  | 3   | R14, R18, R21 | RES., 1M $\Omega$ , 1%, 1/16W, 0402  | Vishay Dale CRCW04021M00FKED              |
| 20  | 3   | R15-R17       | RES., 1.5k $\Omega$ , 1%, 1/16W, 0402  | NIC NRC04F1501TRF                         |
| 21  | 1   | RS1           | RES., SENSE, 0.01 $\Omega$ , 1%, 1/3W, 0603  | SUSUMU PRL0816-R010-F-T1                  |
| 22  | 1   | U1            | IC,2.5A Supercap Backup Power Manager  | LINEAR TECHNOLOGY LTC4041EUFD#TRPBF       |
| <b>Additional Demo Board Circuit Components</b> |     |               |  |   |
| 23  | 0   | C4, C7, C10   | CAP, OPTION, 0402  |   |
| 24  | 0   | R7,R8         | RES., OPTION, 0402   |   |
| 25  | 0   | R12, R13      | RES., OPTION, 0603   |   |
| <b>Hardware: For Demo Board Only</b>            |     |               |  |   |
| 26  | 2   | D1, D2        | LED,SUPER YELLOW, MILKY WHITE DIFF, 0603 SMD   | LUMEX SML-LX0603SYW-TR                    |
| 27  | 1   | D3            | LED, RED, WATER CLEAR, 0603  | LITE-ON TECHNOLOGY CORP LTST-C193KRKT-5A  |
| 28  | 19  | E1-E19        | TEST POINT, TURRET, 0.094", MTG. HOLE  | MILL-MAX 2501-2-00-80-00-00-07-0          |
| 29  | 4   | E20-E23       | CONN., BANANA JACK, FEMALE, THT, NON-INSULATED, SWAGE  | KEYSTONE 575-4                            |
| 30  | 2   | JP1, JP2      | CONN., HDR, MALE, 1 $\times$ 3, 2mm, THT, STR, NO SUBS. ALLOWED                              | Würth Elektronik 62000311121              |
| 31  | 1   | LB1           | LABEL SPEC, DEMO BOARD SERIAL NUMBER   | BRADY THT-96-717-10                       |
| 32  | 4   | MP1-MP4       | STANDOFF, NYLON, SNAP-ON, 0.625"   | KEYSTONE 8834                             |
| 33  | 1   | SW1           | SWITCH SLIDE DPDT 300MA 6V   | C&K JS202011CQN                           |
| 34  | 2   | XJP1, XJP2    | CONN., SHUNT, FEMALE, 2 POS, 2mm   | Würth Elektronik 60800213421              |

# DEMO MANUAL DC2642A

## PARTS LIST

| ITEM   | QTY | REFERENCE    | PART DESCRIPTION                                | MANUFACTURER/PART NUMBER            |
|--|-----|--------------|---|-------------------------------------|
| <b>DC2642A-A Required Circuit Components</b> |     |              |   |                                     |
| 35   | 1   | R9           | RES., AEC-Q200, 1.5M $\Omega$ , 1%, 1/16W, 0402 | Vishay Dale CRCW04021M50FKED        |
| 36   | 1   | R10          | RES., 324k $\Omega$ , 1%, 1/16W, 0402           | NIC NRC04F3243TRF                   |
| 37   | 1   | R19          | RES., 0 $\Omega$ , 1/10W, 0603                  | YAGEO RC0603FR-070RL                |
| 38   | 0   | R20          | RES., OPTION, 0603                              | -                                   |
| 39   | 2   | SCAP1, SCAP2 | CAP, 10F, ULTRA, 2.7V, -10/+20%, THT, RADIAL    | NESSCAP CO. LTD. ESHSR-0010C0-002R7 |
| 40   | 0   | SCAP3        | CAP, 10F, ULTRA, 2.7V, -10/+20%, THT, RADIAL    | NESSCAP CO. LTD. ESHSR-0010C0-002R7 |
| <b>DC2642A-B Required Circuit Components</b> |     |              |   |                                     |
| 41   | 1   | R9           | RES., 698k $\Omega$ , 1%, 1/16W, 0402           | Vishay Dale CRCW0402698KFKED        |
| 42   | 1   | R10          | RES., 348k $\Omega$ , 1%, 1/16W, 0402           | KOA SPEER RK73H1ETTP3483F           |
| 43   | 0   | R19          | RES., OPTION, 0603                              |                                     |
| 44   | 1   | R20          | RES., 0 $\Omega$ , 1/10W, 0603                  | YAGEO RC0603FR-070RL                |
| 45   | 0   | SCAP1, SCAP2 | CAP, 10F, ULTRA, 2.7V, -10/+20%, THT, RADIAL    | NESSCAP CO. LTD. ESHSR-0010C0-002R7 |
| 46   | 1   | SCAP3        | CAP, 10F, ULTRA, 2.7V, -10/+20%, THT, RADIAL    | NESSCAP CO. LTD. ESHSR-0010C0-002R7 |





**ESD Caution**

**ESD (electrostatic discharge) sensitive device.** Charged devices and circuit boards can discharge without detection. Although this product features patented or proprietary protection circuitry, damage may occur on devices subjected to high energy ESD. Therefore, proper ESD precautions should be taken to avoid performance degradation or loss of functionality.

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